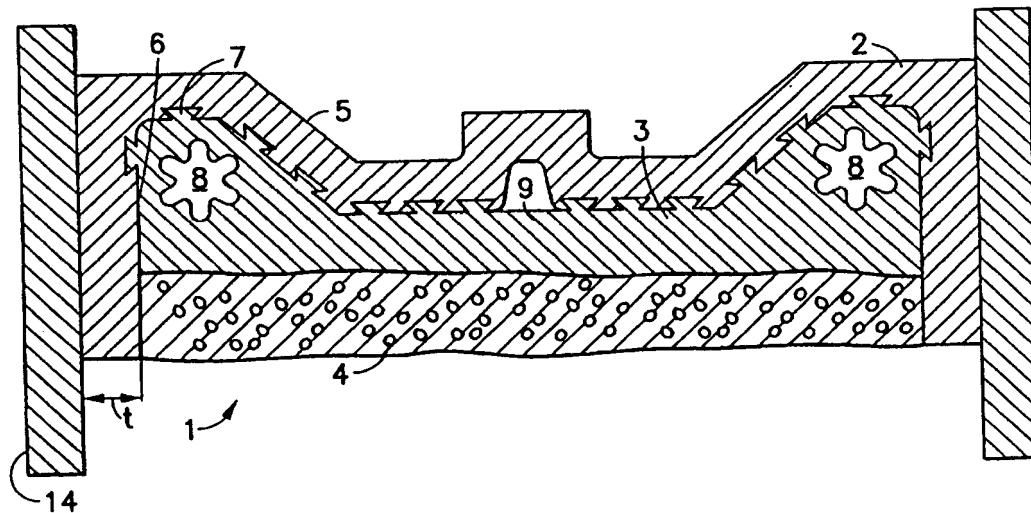


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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## (54) Title: THERMALLY EFFICIENT MOLD APPARATUS AND METHOD



## (57) Abstract

A mold insert or tool (1) of this invention is constructed having an active surface (5) formed on a thin shell (2) from a hardened tool material, thermal management passages (8) molded into the back of the active surface element (2) in an arrangement which substantially conforms to the thermal stress lines generated by the shape of the active surface (5), a copper thermal management layer (4, 9) to enclose the thermal management passages (8), and to add structure to the mold insert (1).

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**THERMALLY EFFICIENT MOLD APPARATUS AND METHOD**

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### **Background of the Invention**

Many products required by today's markets are made by molding parts of plastic and other materials. One of 5 the most costly and time consuming steps in the manufacture of these products is the preparation of molds. A mold insert generally consists of an active surface which contains the contours critical to accurate replication of the product, partings lines at which the 10 mold inserts mate, and a body which provides structural integrity to the mold insert. These components are cast as a block and then machined. In order to achieve molds having active surfaces that provide accurate reproduction of the product with every manufacturing cycle, the active 15 mold surface must have a hard detailed finish which in most processes requires complex and time consuming machining. Such molds or tools must be long lasting so that their cost can be amortized over as large a number of manufacturing cycles as possible.

20

In today's world of computer aided design and modeling almost every step in the manufacturing process has been upgraded to high speed operations. This 25 presents a real dilemma for the tool maker, as the long periods required for the making of molds is more conspicuous. Tool making has become the only low speed operation in the manufacturing process. For example, a typical tooling operation may require 12 to 18 weeks preparation time. Tooling is also recognized as one of 30 the most expensive of the preproduction investments. It is the purpose of this invention to provide a high speed method of tool making at reduced cost. In addition, a tool is provided which minimizes the need for extensive

finish machining by obtaining near net shape from a casting process.

There is a general reluctance to stray from the well 5 established mold making procedures which have provided molds which have proven durable, reliable and provide demonstrated accuracy. A majority of the tooling being manufactured relies heavily on elements which require significant machining to obtain an accurate active mold 10 surface. This requires the use of a machinable material, generally steel, for the tooling components. These processes waste large quantities of material, sacrifice cooling optimization, require an inordinate amount of time, and are expensive.

15 It is the purpose of this invention to rapidly provide near net shape cast mold inserts which minimize machining and reduce cost. The mold inserts of this invention are also designed to maximize cooling through the use of high thermal conductivity materials and 20 conformal cooling that reduces the thermal stresses of the mold insert.

In order to clarify the description of the invention which follows, the basic elements of the shape forming tools need to be identified. For the purpose of 25 illustration, the invention is described in the context of the casting of mold inserts used in the injection molding of plastic articles. Since the item being described is a mold which is itself cast from a mold, the clear designation of the parts is essential for 30 understanding. The mold inserts which are being cast in the method of this invention have active surfaces which mirror the contour of the article to be eventually formed. The metal mold inserts are referred to as a

core and a cavity which are assembled along mating parting surfaces. It should be understood that the mold inserts and process of this invention may be used for a wide variety of casting and molding applications.

5

One method of forming the core and cavity is investment casting. Conventional investment casting involves a time consuming construction of a wax pattern mold. It is the purpose of this invention to use a simplified and more rapid process of investment casting. The general sequence in the standard investment casting process consists of: making steel or aluminum molds from which a wax pattern of the final production article is formed; the wax pattern is coated with a ceramic slurry and hardened to form a ceramic shell enclosing the wax pattern; the wax pattern is then heated to remove the wax from the ceramic shell; the now hollow ceramic shell is then fired to obtain the necessary hardness and filled with molten metal to form a metal casting; and the ceramic shell is then broken to release the metal casting. This positive element, thus formed, is then used to cast the molds for the article, i.e., negative forms of core and cavity. It should be noted that the core and cavity formed in this manner generally consist of a solid block of hardened tool material. It is the purpose of this invention to utilize computer modeling to form an equivalent of the wax pattern directly, thereby eliminating the need for steel or aluminum wax pattern molds and accelerating the investment casting process. This will reduce the time required for the overall mold making process and allow a flexibility in mold design that was not heretofore available.

The present state of the art has sacrificed the

thermal efficiency of the mold inserts through the use of tool steel as the primary construction material. Although having the required hardness, such steels exhibit poor thermal conductivity when compared to copper 5 and even aluminum. This inhibits the thermal efficiency of the completed tool. It is desirable to remove the heat of the molten plastic as quickly as possible to obtain rapid and even solidification of the plastic part and to minimize lingering hot spots. This will improve 10 the mold cycle time and the accuracy of the parts produced. It is the purpose of this invention, to conveniently employ materials of high thermal conductivity and to construct cooling channels which conform to the high thermal stress lines of the active 15 surface of the mold. In this manner the thermal efficiency of the mold inserts of this invention will be superior to the tools of the prior art.

#### **Summary of the Invention**

20 A mold insert or tool of this invention is constructed having; an active surface formed as a thin shell from a hardened tool material, cooling passages molded into the back of the active surface element in an arrangement which substantially conforms to the thermal 25 stress lines generated by the shape of the active surface, a copper cooling layer to enclose the cooling passages, and to add structure to the mold insert.

The thin shell active surface element is formed from 30 a computer generated positive model of the end article which is generated through state of the art CAD/CAM or similar computer modeling techniques. From this model, a stereolithography file (STL file) is constructed which represents an accurate depiction of the active surface

shell. The STL file allows the creation of a pattern of the active surface shell consisting of a thin skin supported internally by a honeycomb like structure. It is the pattern that is used to investment cast the active 5 surface shell. With the stereolithography process, it is possible to include engagement channels, such as dovetail slots, on the back of the active surface element to assist in obtaining a dependable bond with an applied thermally conductive layer.

10

The active surface shell is mounted in an appropriate spray box for additional processing to complete the mold insert. Using finite element analysis based on the computer model, the active surface element 15 is thermally analyzed to identify the optimum location for cooling channels. Either bent copper tubing or an extruded wax mandrel of the cooling channel is constructed and arranged on the back of the active surface element to conform to the location of the maximum 20 thermal stresses. In this manner the cooling efficiency of the channels is optimized. Once the cooling channels are arranged, a copper thermal layer is applied by spraying to encapsulate the cooling channels and provide structure to the active surface element. The combination 25 of conformal cooling channels in a copper matrix creates a very effective cooling layer. To complete the mold insert the active surface shell and copper cooling layer is further supported by further application of sprayed copper behind the cooling layer.

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After the mold insert is removed from the spray box, it may be machined, as needed, to improve the accuracy of the active surface. In general a tolerance of  $\pm .020$  inches is reasonably obtainable from the investment

casting process. A further machining step is needed to bring the active surface to within a tolerance of  $\pm .005$  inches as generally required for quality tooling. The end result is a durable mold insert which provides  
5 superior cooling properties in a more rapid time frame.

#### Description of the Drawing

The invention is described in more detail below which reference to the attached drawing in which:

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Figure 1 is a schematic view of the cooling configuration of the prior art;

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Figure 2 is a schematic view of the cooling configuration of this invention;

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Figure 3 is a cross sectional view of the mold insert of this invention;

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Figure 4 is a cross sectional view of the stereolithography pattern used in the casting process of this invention;

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Figure 5a is a cross sectional view of the engagement slots of this invention;

Figure 5b is a plan view of the back of the active surface element of this invention showing the engagement slots; and

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Figure 6 is a cross sectional view of the conformal cooling passages of this invention.

### Detailed Description of the Invention

As shown in figure 3, the mold insert 1 of this invention consists of an active surface shell 2, cooling layer 3, and a structural backing 4. Active surface shell 2 is constructed of hardened tool material, such as steel or beryllium-copper, having a uniform thickness (t). The active surface 5 forms the tool face. The back face 6 of the active surface shell 2 is formed with slots 7 having a dove tail cross section to enhance bonding of the cooling layer 3. The slots may be formed in a variety of cross sections and arrangements as shown in figures 5a and 5b.

Cooling layer 3 consists of cooling passages 8 which are arranged to substantially conform to the thermal stress lines of the active surface shell 2. The passages are formed from bent copper tubing or extruded flexible mandrels which can follow the contours of the active surface shell 2, where necessary, to remove hot spots and promote efficient cooling. In the prior art, these passages generally must be formed in a solid block of steel which is the mold insert. The passages must be formed by drilling and are therefore limited to straight passages having a circular cross section, as shown in figures 1 and 6. These straight passages limit the positioning of the channels 8 and prevent access of cooling media to the most critical thermal zones. Through the use of flexible extruded mandrels and a sprayed cooling layer, a passage cross section can be constructed having an extended surface area such as the star shape shown in figures 3 and 6. This maximizes the cooling performance of the cooling passages 8. In addition the channels or passages 8 may be arranged to provide cooling media to the zones of the mold insert 1

that are at the highest thermal stress.

To complete the cooling layer, a material 9, having high thermal conductivity such as copper or aluminum, is 5 sprayed to a thickness which encloses the cooling channels 8. The application of the copper or aluminum will fill the engaging slots 7, thereby improving the integrity of the bond between the active surface element 2 and the cooling layer 3. These channels under some 10 conditions could be used for heating as well and may be appropriately referred to as thermal management channels.

A backing layer 4 is bonded to the cooling layer 3 and is constructed of additional sprayed copper or 15 aluminum. It should be noted that although spraying is specified any appropriate deposition method may be employed.

It is desired in this invention to reduce the amount 20 of tool material required for a mold insert, including the amount of such materials removed through either CNC machining or EDM. To accomplish this purpose, the active surface shell 2 is investment cast as a thin shell using computer aided processes such as: QUICKCAST® or ACTUA- 25 2100 developed by 3D Systems, Inc. and MODELMAKER developed by Sanders Prototyping, Inc. Investment casting in general and the computer aided processes in particular works best when the sections to be cast are as close to uniform thickness as possible. Although, such 30 methods have been used to cast mold inserts, it is a unique application of these processes to form only a thin shell active surface.

According to this invention, Computer Aided Design (CAD) techniques are used to digitally define a computer model of the active molding surface of both the core and cavity. Using recently developed CAD methods, an active 5 surface shell is generated which extends uniformly back a given thickness from the active surface, for example, from 1 to 100 mm thick. Ideally, an active surface element of, from 3mm to 20 mm thick, would be generated in the model.

10

The investment casting process is generally time consuming and expensive because the wax patterns require the fabrication of wax injection tooling prior to the investment of the wax pattern in ceramic slurry. Through 15 the use of the methods, such as QUICKCAST, the computer model is used to construct the equivalent of a wax model or pattern by stereolithography (STL). In the process of this invention, pattern 10 of the active surface shell 2 is generated which consists essentially of an exterior 20 skin 11, which is less than 1 mm thick. The skin 11 is supported internally by a quasi-hollow honeycomb-type structure 12, shown schematically in Figure 4. The STL pattern 10 is then used to investment cast active surface shell 2, thereby entirely bypassing the expensive and 25 time consuming step of fabricating steel or aluminum wax pattern injection tooling.

Investment casting, however, is not capable of achieving the accuracy levels needed to meet the 30 tolerances of production tooling, but an active surface geometry within .040 inches at all locations, and within .020 inches at the majority of locations is achievable. Such tolerances may be classified as "Near-Net" since the dimensions, while not perfectly accurate, are indeed very

near the desired or "Net" shape. The active surface 5 must still be machined as a final finishing step to obtain the desired tolerance of  $\pm .005$  inches.

5 Utilizing computer aided design techniques, the process of this invention begins with the generation of a computer model of the article which is eventually to be formed from the mold apparatus of this invention. From 10 this data, a model of the active surface 5 of core and cavity is generated through well known techniques. The active surface 5 is then given three dimensional properties, namely a thickness, and a CAD model of the active surface shell 2 is generated. The thickness of 15 the shell 2 is selected to allow final machining of up to 1mm of material. To create a strong mechanical bond, the back surface 6 of the shell 2 is designed to include a series of interlocking dove-tail channels, as shown in figure 5a and 5b. The ease of incorporating such channels in mold systems is one of the advantages of 20 adapting computerized processes to the application of this invention. Such a configuration would be difficult and prohibitively expensive to machine.

25 The completed computer model of the active surface element may now be converted to a stereolithography file or STL file and the pattern 11 is constructed. The pattern 11 is then used in the investment casting process, as described earlier. A steel hardened tool or 30 material embodiment of the active surface shell 2, including the dovetail channels, is thereby obtained. The active surface shell 2 is then mounted in a spray box 14. The spray box 14 is constructed such that the resulting mold element or insert 1 is compatible with 14. standard mold bases.

Using the data obtained from the computer model of the active shell 2, finite element analysis can be used to map the location of the projected thermal stresses to 5 which the element 2 will be subjected during use. The resulting isotherms will locate the optimum position of cooling channels 8. From this information, a computer model of the conformal cooling channel configuration 15, as shown in figure 2, is generated.

10

Conformal cooling passages 15 maybe formed by bending thin walled refrigerator copper tubing to the desired shape. The cooling passages 8 may also be formed from extruded wax mandrels, which are arranged along the 15 isotherms of the thermal map. The extruded wax mandrels may include hollow central regions. Furthermore, the cross sections of said wax extrusions need not be circular, or annular, but may be of any shape that improves the cooling of the mold, while said shape should 20 also simultaneously be readily extruded. An example of a cooling passage having a non-circular cross-section is illustrated in Figure 6.

From the computer model of the cooling channels 8, 25 an STL file is generated which forms the basis for a jig. The jig is built through stereolithography and is then used to assure that the geometry of cooling passages 8 is indeed accurate in all dimensions within +/- 0.5 mm. Errors greater than +/- 0.5 mm become visible air gaps 30 between the passage extrusions and the jig.

The resulting cooling passage configuration 15 is then positioned, within the spray box 14, on the back surface of the active surface element 2. Dimensional

registration of the cooling passage configuration 15 may be accomplished by means of copper tie-rods (not shown) which secure the supply tubing to the "Spray Box 14.

5

Next the back 6 of the active surface shell 2, including the adjacent cooling passage configuration 15 and tie-rods, are sprayed with molten, atomized, copper droplets. This spraying operation is continued until all 10 portions of the conformal cooling passages 8 are completely encased within solidified copper cooling layer 3. Any suitable material may be used that is an efficient thermal conductor. In addition, a suitable deposition process can be employed other than spraying.

15

When the conformal cooling configuration 15 is enclosed, the copper spraying is continued to fill the remainder of the spray box 14 to form a backing layer 4 for the mold insert 1. After complete cooling of the 20 backing material, the excess can be quickly machined away, providing a flat surface to mate with a standard tooling base. Other backing materials may be used such as powdered aluminum in an epoxy matrix or similar composite materials having good thermal conductivity.

25

In this manner a mold is constructed having an active surface shell made from tool steel, Beryllium-copper, or appropriate hardened tool material. Tool performance is, therefore, at least comparable to 30 conventional tool steel molds or potentially superior for the case of beryllium-copper. The finish machining will be virtually identical to conventional tool making, resulting in ready acceptance by standard tool and die shops. Because the active surface 2 is very close to

the final dimensions of the active surface of either the core or cavity, only a minimum amount of material need be removed by machining.

5        The tool is backed with a substantial amount of copper resulting in an enhanced overall thermal conductivity relative to conventional tools made entirely from tool steel.        Because the overall thermal conductivity of the composite tool is enhanced, it will  
10      conduct heat away from the hot injected plastic or metal more rapidly, leading to reduced cycle times and enhanced productivity.    Through the use of conformal cooling, the generation of local hot spots will be reduced, leading to additional gains in productivity.

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      The use of an STL jig virtually assures that the conformal cooling passages faithfully replicate the CAD / FEA design, which will promote a more uniform cooling of the injection molded material. Distortions resulting from  
20      nonuniform shrinkage will be reduced, thereby obtaining more consistently accurate end products.

      The only steps of this process which are time consuming are the investment casting of the active  
25      surface shell 2 and the subsequent finish machining of the active surfaces.    A majority of the steps are computer controlled and facilitated which results in a considerable savings in time and expense.    The use of an assembly of layers to form the mold insert, namely;  
30      active surface shell, cooling layer with imbedded cooling passages, and structural backing layer allows the efficient use of computerized processes to obtain the advantages of this invention.

**Claims**

We Claim:

5        1. In an apparatus for molding plastic articles including a positive model of the plastic article and a mold insert, said mold insert comprising:

10        a computerized data file representing a negative model of at least a portion of said plastic article;

a thin shell having an active mold surface formed thereon based on said negative model representation;

15        a thermal management section formed on the back of said active surface and constructed of a highly thermally conductive material said thermal management section having channels arranged therein to conform substantially to the lines of thermal stress of the mold insert;

20        a structural section formed on the back of the thermal management section and constructed of a highly thermally conductive material.

25        2. In an apparatus for molding plastic articles including a positive model of the plastic article and a mold insert, said mold insert as described in claim 1 wherein the thermal management channels are arranged in accordance with a thermal stress map derived from the 30 computerized data file.

3. A method of constructing a mold insert with a thin shell having an active surface, a thermal management

section and a structural backing section, said mold used in the manufacture of articles comprising the steps of:

5 defining a computerized data file representing at least a portion of the article to be manufactured;

defining a computerized model of a negative active mold surface from said computerized representation;

10 forming a thin shell having an active mold surface based on said computerized model;

15 deriving a computerized data map of the thermal stress lines based on said computerized model of said active mold surface; and

20 forming a thermal management section on the back of said thin shell wherein channels are arranged in substantial conformity to the stress lines in accordance with said computerized data map.

4. A method of constructing a mold insert with a thin shell having an active surface, a thermal management section and a structural backing section, said mold used in the manufacture of articles, as described in claim 3 25 wherein the step of said thin shell comprises:

30 using said computerized model of the active mold surface, construct a positive model of the active surface by means of a stereolithographic process; and

forming said thin shell by means of investment casting based on said active surface model.

1/3

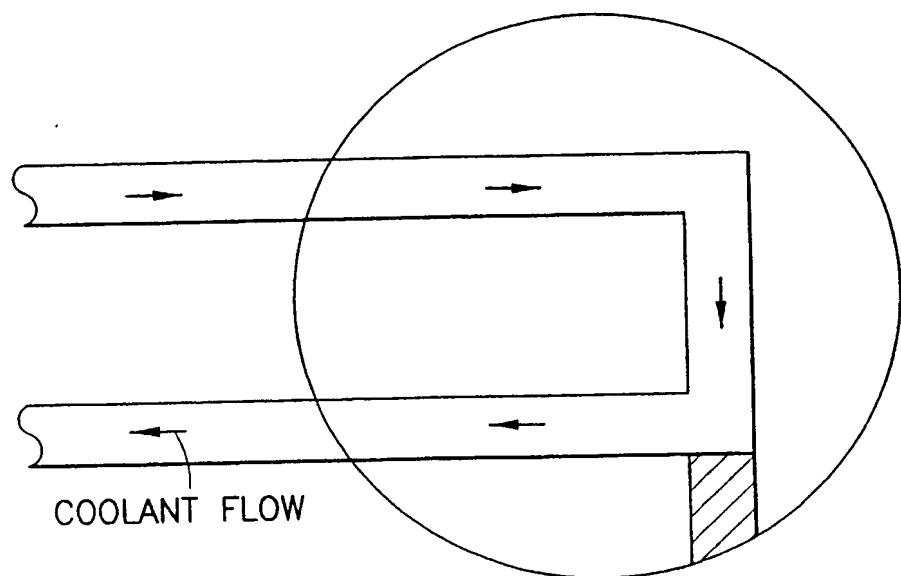


FIG.1

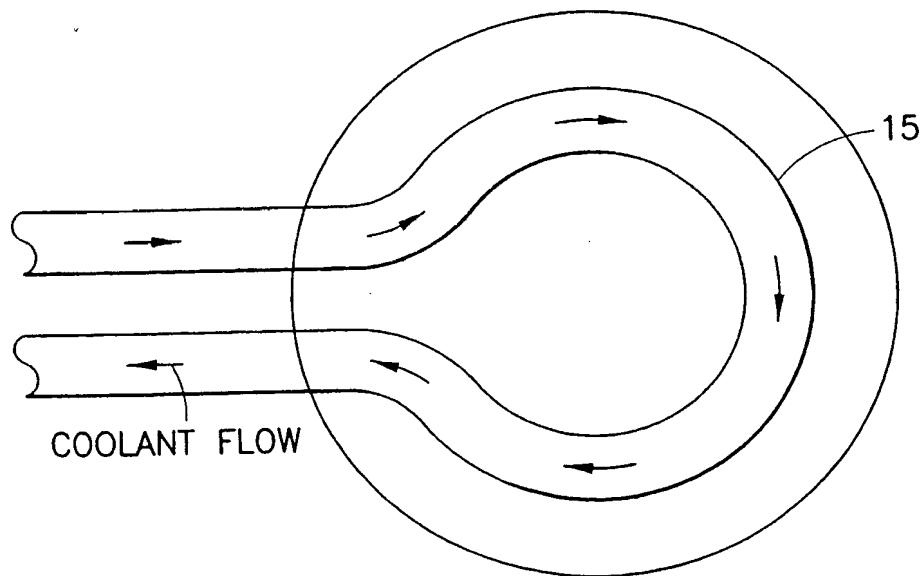


FIG.2

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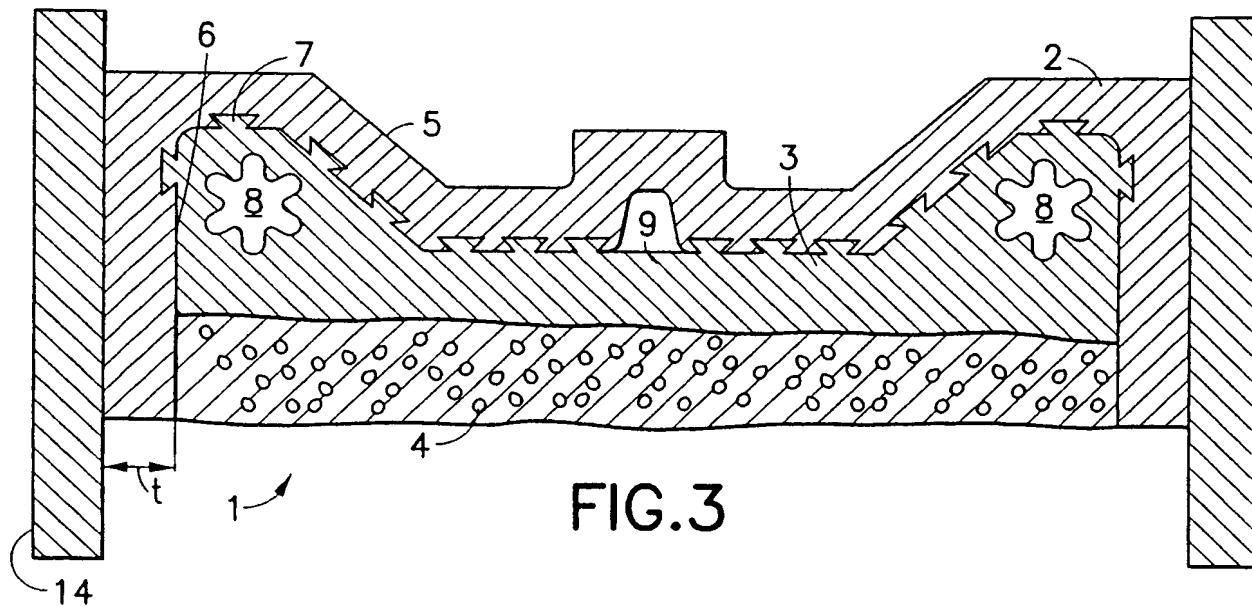


FIG. 3

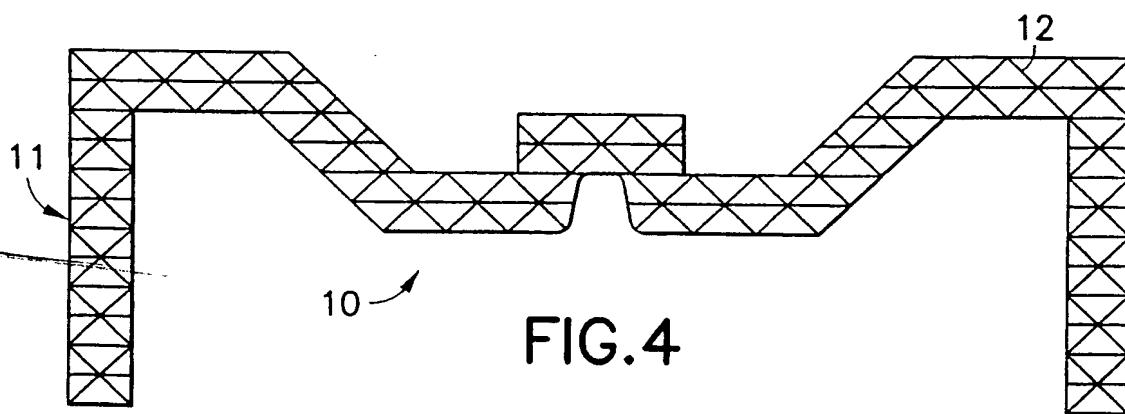


FIG. 4

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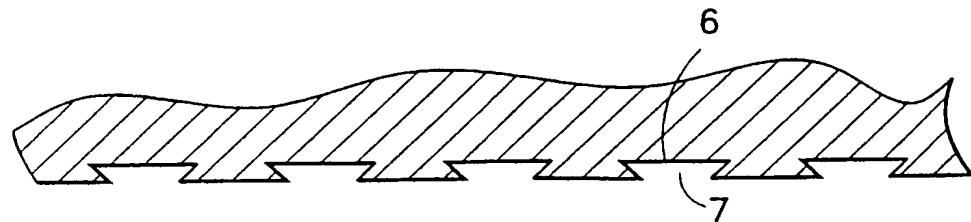


FIG.5A

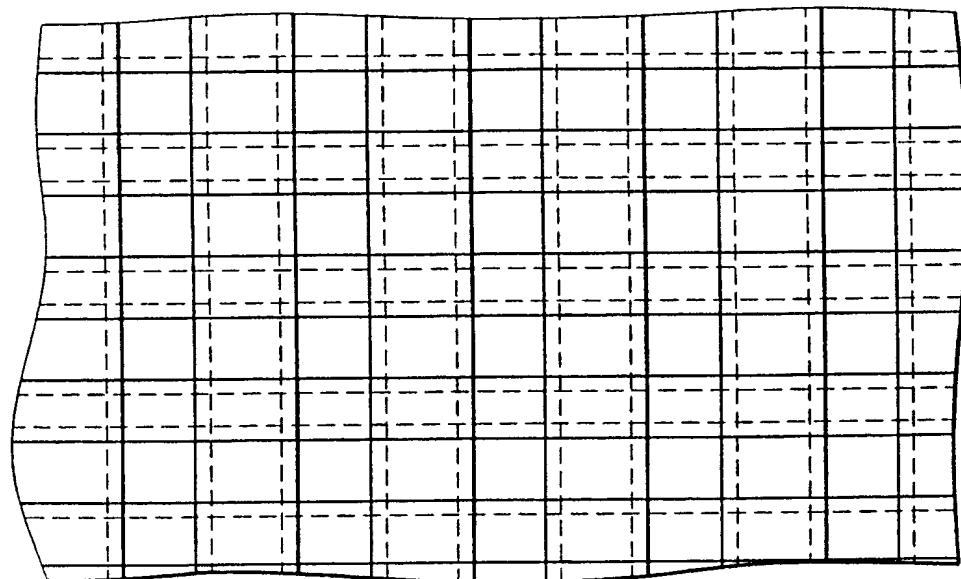


FIG.5B

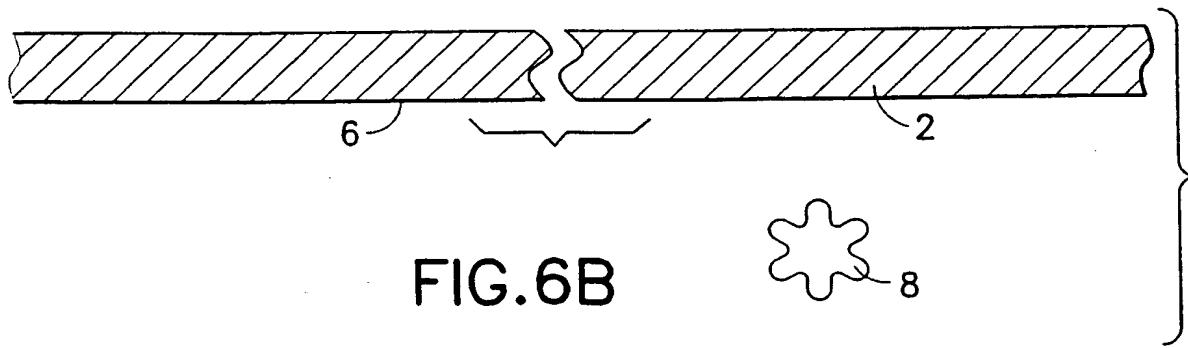
FIG.6A  
PRIOR ART

FIG.6B

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/02565

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : B29C 33/04, 33/38

US CL : Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 164/4.1, 19, 23, 45; 249/79, 80; 264/219, 220, 221, 348, 401; 425/175, 552; 364/468.26, 468.27

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,189,781 A (WEISS et al.) 02 March 1993 (02-03-93), Figure 4, column 4, lines 5-19.	1
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Y		2-4
Y, P	US 5,849,238 A (SCHMIDT et al.) 15 December 1998 (15-12-98), column 4, line 31 through column 5, line 17.	2-4
Y, P	US 5,775,402 A (SACHS et al.) 07 July 1998 (07-07-98), column 6, lines 15-38.	2-4
Y	US 3,811,175 A (GARNER et al.) 21 May 1974 (21-05-74), column 2, lines 35-39.	2-4
A	US 5,437,547 A (HOLTON et al.) 01 August 1995 (01-08-95).	1-4
A	US 3,723,584 A (NUSSBAUM) 27 March 1973 (27-03-73).	1-4

Further documents are listed in the continuation of Box C.  See patent family annex.

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Date of the actual completion of the international search

28 MARCH 1999

Date of mailing of the international search report

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## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,169,549 A (WEBER) 08 December 1992 (08-12-92).	1-4
A	US 5,658,506 A (WHITE et al.) 19 August 1997 (19-08-97).	1-4
A	US 4,844,144 A (MURPHY et al.) 04 July 1989 (04-07-89).	1-4

Form PCT/ISA/210 (continuation of second sheet)(July 1992)★

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/02565

A. CLASSIFICATION OF SUBJECT MATTER:  
US CL :

164/4.1, 19, 23, 45; 249/79, 80; 264/219, 220, 221, 348, 401; 425/175, 552; 364/468.26, 468.27